PERFORMANCE CHART IMPROVEMENT FOR THE POST PA5140 P-3C/W ORION AIRCRAFT

(Paper # 1)

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ABSTRACT

This Seminar Paper is an insight into the work conducted by the authors for the ‘High Drag and Vibration Investigation – Phase 2’ (HDVI) directed by the Maritime Patrol Logistics Squadron, Royal Australian Air Force.

The focus of this paper is to present results obtained so far in producing performance charts for the recently modified P-3C/W Orion fleet, and the procedures followed by the authors during this project. The production of the performance charts was divided into three main sections…

1. Review of existing drag reports, in particular the Barlow Model
2. Collection and Manipulation of data relevant to the P-3C/W profile drag, and…
3. Data Analysis and Graph plotting

KEYWORDS:

- Barlow Model
- Flight Engineer Log
- Airframe Characteristics
- Engine Performance Characteristics
- SGR Graphs.

1. INTRODUCTION.

Some years ago the RAAF P-3C/W Orion fleet was fitted with an upgraded ESM system generally referred to as Project Air 5140 (PA5140). Part of the modification included the fitment of antenna arrays to the wing tips and lower fuselage. To achieve the required degree of electronic sensitivity it was necessary that aerodynamic efficiency be compromised. This has resulted in the rather unusual wingtip shape and bluff body plinth and antenna arrangement on the lower fuselage.

Since the installation, pilots have reported unusual vibrations during certain manoeuvres and increased drag as evidenced by higher fuel flows to achieve the same performance as the pre-modification aircraft. A post-modification analysis calculated the increased drag to be 4.5%, however a review of this analysis suggests that this figure is questionable and likely to be optimistic. Since then, Phase 1 of the HDVI (AUG99 – NOV00) has established the high-drag and vibration claims to be true. Phase 2, currently in motion (FEB01 – NOV01), will ascertain the cause of the vibration and high drag phenomena, which at present is believed to be the result of an irregular airflow regime around the aircraft as a consequence of the PA5140 modifications.

The change in profile, and therefore aerodynamics, of the aircraft has meant that the Lockheed pre-PA5140 performance charts in the current P-3C/W flight manual can be assumed to be no longer accurate.

AIM: therefore, the overall aim of the project is to **prepare updated drag curves to reflect the Project Air 5140 (PA5140) modified aircraft** for possible inclusion into the P-3 Orion Flight Manual.

2. BARLOW MODEL.

In 1994 Dr. S. Barlow of the RAAF Aircraft Research and Development Unit (ARDU) developed a methodology for calculating aircraft drag from the records taken by Flight Engineers in the course of their normal duties. As these recordings are taken each flight, a considerable body of data is rapidly accumulated. This method was applied to the RAAF C-130E Hercules fleet and its results were used to form new Specific Air Range graphs to be incorporated into the C-130E Flight Manual.

The project conducted by the authors was to apply this methodology to the post PA5140 modified P-3 aircraft to provide a better estimation of the real drag differential generated by the modification.

2.1 Barlow Review

The model was initially reviewed by the authors to determine whether this methodology was suitable for the P-3C/W Orion fleet, and to determine if any alterations were required. A comparison model was also constructed using the Roskam method [ref[4]] for determining cruise performance in relation to airframe characteristics.

As previously mentioned, the model was designed such that the performance data required for computation could be easily extracted from the Flight Engineer Logs. The relevant data parameters for the Barlow Model are…

- True Airspeed (kts),
- Calibrated Outside Air Temperature (°C),
- Pressure Altitude (ft),
- Engine Shaft Horsepower (hp),
- Zero Fuel Weight (lbs),
- Fuel Quantities (lbs),
- And, Fuel Flow (lbs/hr).

The most important mathematical results from the Barlow Model are shown below…

Airframe Characteristics:

$$SHP_{ew} * V_{ew} = k_1 V_{ew} + k_2 \qquad \text{...[1.]}$$

where… SHP_{ew} = Shaft Horsepower (equivalent weight)

V_{ew} = Velocity (equivalent weight)

k_1 = Profile Drag Coeff.

k_2 = Induced Drag Coeff.

Engine Performance Characteristics:

$$\frac{W_f}{\delta\sqrt{\theta}} = k_3\left(\frac{SHP}{\delta\sqrt{\theta}}\right)^2 + k_4\left(\frac{SHP}{\delta\sqrt{\theta}}\right) + k_5 \quad \text{...........................[2.]}$$

where… k_3, k_4 and k_5 are referred fuel flow coeffs.

$$\frac{TIT}{\theta} = k_6\left(\frac{SHP}{\delta\sqrt{\theta}}\right) + k_7 \quad \text{...........................[3.]}$$

where… k_6 and k_7 are referred turbine inlet temp. coeffs.

2.2 Roskam Review

The Roskam Model is very similar to the Barlow Model in composition and a number of values can also be taken from the Flight Engineer logs. It was determined from a design approach, as opposed to Barlow's model that was determined from a developmental point of view. The model calculates the range for the aircraft for a finite distance (500 nm) to find the lift coefficient, and similar to Barlow uses the equation of a line to find the induced and profile drag, which are represented by coefficients.

The Roskam model requires:

-Cruise speed
-Cruise altitude
-Fuel usage
-Engine efficiency

The important mathematical results of the model are shown below.

$$C_D = C_{D_{min}} + K''\left(C_L - C_{L_{min}}\right)^2 + K'C_L^2 \quad \text{..............................[4.]}$$

where… K' and K'' are drag factors

C_L = Lift Coeff.

C_{Lmin} = Lift Coeff. (min. viscous lift drag)

C_{Dmin} = Drag Coeff. at C_{Lmin}

3. DATA COLLECTION AND MANIPULATION

3.1 Data Collection

Most of the data was taken from the Flight Engineer Logs (FLTENG Logs), which covered a period of 5 years (1996-2001). These were sampled from approximately 70% of the fleet. Some aircraft from the fleet have been on overseas service or in storage at Avalon for long periods of time, therefore data collection from these aircraft has proven fruitless.

The data was broken into two main categories for analysis: level flight power required (airframe characteristics), concerning parameters such as atmospheric conditions, airspeed and aircraft weights; and engine performance (engine characteristics), regarding parameters such as TIT and fuel flow. The data was then manipulated on MS Excel.

3.2 Data Manipulation

The original statistical design for the airframe characteristics was to divide the data into aircraft tail number, find the parameters and then find a fleet wide mean value for the profile and induced drags. However, due to the low number of data points (n=533), the data from all aircraft was combined to determine the airframe characteristics fleet wide and analysed collectively, at the expense of data control, but not stability. From the results obtained from the model, it can be seen that the modified P-3x model was robust enough to provide a practical fleet trend. A statistical analysis of the results was conducted to account for any large variances or shifts in data that could occur from this practice.

The engine characteristics were determined across the fleet with each engine entry entered into the model separately (i.e. four per log entry); therefore there is four times as much engine data as there is airframe data.

Results so far have been encouraging, particularly in comparison with Barlow's C-130E results. The C130E as a transport craft usually flies at a certain altitude, constant shaft horsepower setting, and hence speed until its destination is reached. The P-3 aircraft, as a surveillance platform, will regularly change its altitude, shaft horsepower and speed throughout a sortie. From the point of perspective of Barlow's C-130E results, the P-3C/W aircraft incurs less profile and induced drag (i.e. the Orion is lighter and sleeker in profile than the C-130E).

3.2.1 Airframe Characteristics

'Airframe Characteristics' represent the power required for level flight and can be defined, and hence graphed, in terms of shaft-horsepower and velocity, (SHP_{ew} versus V_{ew}). This equates to energy required to propel the aircraft through a fluid versus the aircraft's drag, which is equal to the magnitude of the velocity vector in the x-direction with convention to earth's surface (profile drag), plus a value proportional to the amount of lift created by the aircraft in motion (induced drag).

To ensure the variability in our data and low number of data points did not cause a large uncertainty in our results, the standard error for each coefficient was calculated. The total error was then calculated to be well under 5%, and hence acceptable.

Results of the Airframe Characteristics (profile and induced drag coefficients) are included as Table 1.

Ws (lbs)	k_1	Standard Err.	Error %	k_2	Standard Err.	Error %
80	1.704E-5	1.589E-7	0.939	117741.157	2498.551	2.122
90	1.704E-5	1.589E-7	0.939	149016.152	3162.229	2.122
100	1.704E-5	1.589E-7	0.939	183970.558	3903.987	2.122
110	1.704E-5	1.589E-7	0.939	222604.375	4723.825	2.122
120	1.704E-5	1.589E-7	0.939	264917.604	5621.742	2.122
130	1.704E-5	1.589E-7	0.939	310910.244	6597.738	2.122

TABLE 1. Profile Drag (k_1) and Induced Drag (k_2) Coefficients

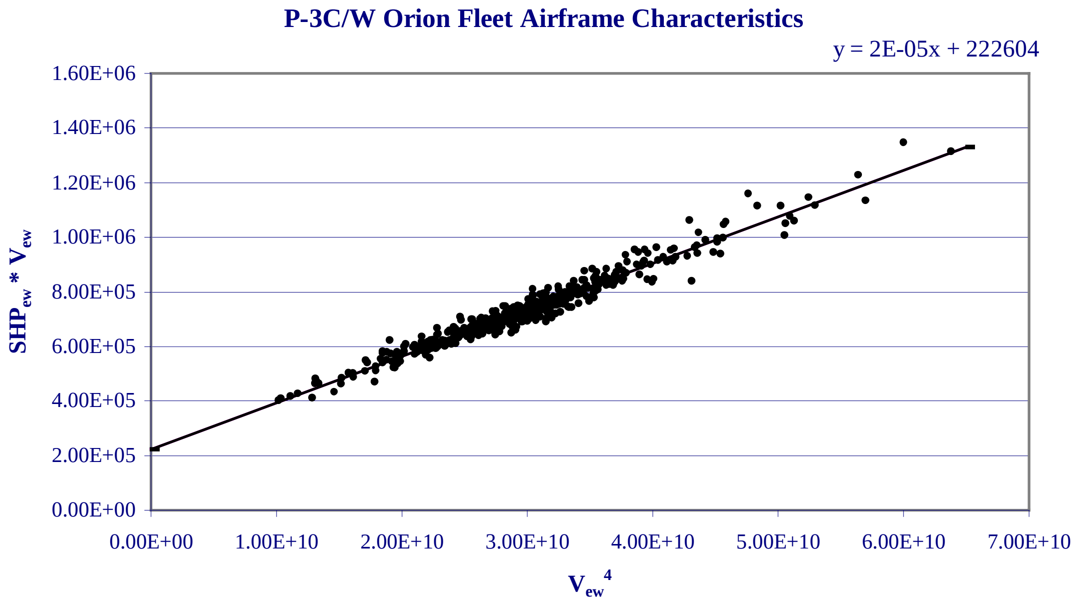

FIGURE 1. Graph of fleet airframe characteristic data ($W_{stan.}$ = 110,000 lbs)

3.2.2 Engine Performance Characteristics

'Engine Characteristics' represent engine performance and can be evaluated by considering the variations of TIT or fuel flow with shaft-horsepower, (TIT_{ref} or F/F_{ref} versus SHP_{ref}). As explained in Appendix C (Barlow Model, Important Mathematical Results), engine performance is considered in terms of referred shaft-horsepower, referred fuel flow (F/F) and referred TIT.

At this stage, results have not been finalised for the Engine Performance Characteristics.

5. DATA APPLICATION

5.1. Graph Plotting

Once the results of the data analysis have been finalized, Specific Ground Range (SGR) graphs will be plotted from an ARDU produced PC software program. After the SGR graphs have been created, it will be important to confirm the legitimacy of our SGR graphs. They can be confirmed by conducting validation flights where performance measurements are taken and compare the aircraft's actual performance with the performance predicted by our model.

Should the SGR graphs provide an improvement over the current flight manual graphs, it will be recommended that the new performance curves be added to the flight manual.

6. ACKNOWLEDGEMENTS

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7. CONCLUSIONS

The SGR graphs will be compared against the existing performance curves in the P-3C/W Orion Flight Manual. If an increase in drag is found and proves to be large, the mission profiles of the P-3 fleet will need to be changed with accordance to the new SGR graphs. The alternative being that the Plinth and wing tips be removed, redesigned. Possibly the most acceptable and cost effective method would be to add faring to the most obvious sources of extra drag.

8. REFERENCES

[1] DI (AF) AAP 7215.004-1, "Flight Manual P-3C Orion".

[2] Dr. S. Barlow, "Performance Chart Improvement – C130E Hercules" ARDU Published (1994)

[3] C. Hammond, and J. Smith, "P-3C Orion Performance Modelling". Mech. Eng. Thesis, University of Adelaide (2000)

[4] J. Roskam, "Airplane Design" Series, 2nd Edition, Self Published (1989)

[5] B.W. McCormick, "Aerodynamics, Aeronautics and Flight Mechanics", John Wiley and Son, USA (1979)

[6] R. Shevell, "Fundamentals of Flight", 2nd Edition, Prentice Hall, USA (1989)